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A CASE STUDY ON GERMANY'S AVIATION TAX USING THE SYNTHETIC CONTROL APPROACH

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Abstract: The German Aviation Tax is a tax levied on departing passengers from German airports. In this paper, we investigate the impact Germany's aviation tax has had on passenger numbers using the synthetic control method to generate counterfactual passenger numbers for German airports, and for airports outside Germany but near the German border. The results are consistent with passengers engaging in cross-border substitution in response to the aviation tax. Most tax exempt airports near German borders have made sizeable gains in passenger numbers since Germany introduced its aviation tax. Within Germany there appears to be a clear distinction in the impact on small/regional airports and that on larger hubs. From a policy perspective, the finding of a cross-border substitution effect implies that the aviation tax might not be effective in curbing overall emissions from air travel, whilst also leading to lost tax revenues through the displacement of passengers to neighbouring countries.

JEL Classification: H26, H30, L93

Keywords: aviation taxes, passenger demand, synthetic control

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1. Introduction

Aviation tax (AT) regimes in Europe receive considerable attention. Germany's AT was introduced on 1st January 2011 and remains payable on departures from all German airports at a cost of €7.50, €22.43, or €42.18 depending on the distance flown[1]. While often motivated as environmental taxes, the common perception is that revenue raising is the key driver of ATs (Zuidberg 2015). In spite of this, experts often question the efficacy of single-country ATs as environmental measures or revenue-raising tools, in large part due to the cross-border tax avoidance opportunities associated with them (Zuidberg 2015, Krenek and Schratzenstaller 2017). Airports and airlines often spearhead campaigns for abolition of ATs, citing adverse effects on demand, competitiveness and connectivity[2]. Germany's Economy Minister is reportedly swaying toward abolition for these reasons[3].

In this paper, we investigate the impact that Germany's AT has had on passenger numbers using German airports and airports outside Germany but near the border (henceforth referred to as bordering airports). Specifically, we use the synthetic control method of Abadie et al. (2010) to construct counterfactual series for each airport of interest, the counterfactual series representing passenger numbers under the alternative scenario that AT was never introduced. The impact of AT is then estimated as the gap between actual passenger numbers since 2011 and the counterfactual numbers.

We estimate changes in passenger numbers that can be attributed to AT for German airports and for bordering airports outside of Germany. Airports are modelled separately to see whether the effects of the AT might differ across airport types. Results indicate more passengers used bordering airports after the introduction of German AT, while most German airports, with the exception of hubs, saw a negative impact of AT on passenger numbers.

Our main contribution is to the literature on the impacts of AT. Case studies focusing on the Dutch AT (introduced in 2008 and abolished a year later) find that the aviation tax led to a significant reduction in passenger numbers at Dutch airports, an increase in passengers at airports in bordering countries (Gordijn and Kolkman 2011), and a reduction in tourism (Mayor and Tol 2010). For the United Kingdom, Seetaram et al. (2014) find that the UK aviation tax (Air Passenger Duty, or APD) was ineffective in reducing demand for air travel

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[1] See Deutsche Bundesregierung (German Federal Government, 2012).
[2] See Edinburgh Airport (2015).
[3] See DW "*German Air Passenger Tax Under Increased Fire*" August 2017.

and passengers were prepared to pay higher prices for flight tickets. Similarly, Mayor and Tol (2007) find that doubling the UK aviation tax did not lead to a reduction in demand, only a substitution from short-haul to long-haul flights. For Australia, Forsyth et al. (2014) estimates that the introduction of the aviation tax will lead to sizable net losses to the tourism industry. Finally, contemporaneously to our study, Falk and Hagsten (2018) assess the impacts of the recently introduced AT in Germany and Austria on passenger numbers at both domestic and bordering airports. They use a panel data difference-in-differences (diff-in-diff) approach with untaxed European airports as the comparison (control) group in order to estimate the effects of AT on passenger numbers. They also distinguish between hubs, low-cost and bordering airports: their main finding is that the AT led to an overall reduction in passenger numbers at Austrian and German airports, but that these results are mostly driven by airports that predominantly serve low-cost airlines. They find no significant impact from the AT on passenger numbers at bordering airports.

Case studies that have assessed the impacts of ATs on passenger numbers have either used a linear extrapolation method (Gordjin and Kolkman 2011) or panel diff-in-diff (Falk and Hagsten 2018) to estimate counterfactual passenger numbers at airports, where the counterfactual approximates passenger numbers under a scenario of no aviation tax. Through our empirical strategy, we contribute to the literature by employing a novel approach to estimate counterfactual passenger numbers at airports. Our empirical approach uses the synthetic control method (Abadie et al. 2010) to estimate counterfactual passenger numbers, and can provide robust estimates of counterfactuals for a number of reasons. First, this method optimises the selection of comparison (control) airports so that counterfactual passenger numbers are based on those control airports most similar to the treated airports in terms of passenger trends. Second, contrary to panel diff-in-diff estimations, synthetic control estimates do not rely on the assumption of parallel trends for treated and control groups (Billmeier and Nannicini 2013). This approach is particularly suitable for our analysis as it allows us to construct reliable counterfactuals using aggregate level data. Indeed, according to Abadie et al. (2015) the most relevant application of the synthetic control method is for comparative case studies that use aggregate data.

Through our findings we also contribute to the literature on the determinants of air passenger demand and airport choice (see for example Graham 2000, Brons et al. 2002, Valdes 2015, or Jankiewicz and Huderek-Glapska 2016). Only a few studies (Pels et al. 1998, Steverink and van Daalen 2011) consider the impact that aviation taxes have on the airport choices of passengers. These studies are however mostly theoretical in their approach. Our paper therefore contributes to the literature by providing empirical evidence that passengers are highly responsive to the introduction of AT, and by finding some evidence (albeit only at the aggregate level) that passengers change airport choices in response to these taxes.

Furthermore, our analysis contributes to the literature on cross-border shopping (Joossens and Raw 1995, Nielsen 2001, Asplund et al. 2007). This strand of the tax policy literature focuses on the way tax differences across borders affect the preferences and choices of consumers. Our results contribute to the literature by finding evidence for a specific case of cross-border shopping: our results show that AT differences across borders can have a noticeable impact on air passenger movements between the bordering countries. More specifically, we find that the introduction of the AT in Germany can be associated with a substantial increase in passengers at tax-free airports near the German border.

The remainder of the paper is organised as follows. Section 2 summarises the relevant conceptual and policy background. Section 3 describes the data and outlines the empirical approach. Section 4 shows the results and assesses the plausibility of our findings. Section 5 provides a discussion of our findings. Section 6 concludes.

2. Conceptual and Policy Background

The German aviation tax (AT) was introduced on 1st January, 2011. The AT is charged after passengers departing from German airports. There are three different tax bands charged based on distance flown with rates set at €7.50, €22.43, and €42.18 for short, medium, and long-distance flights, respectively[4]. According to forecasts by Berster et al. (2010), the number of passengers expected to belong to each tax category was (at the time of introduction) 62.3, 2.9, and 8.9 million, respectively.

We estimate that roughly 84% of passengers can be expected to pay a unit tax of €7.50, 4% of passengers can be expected to pay €22.43, and 12% of passengers can be expected to pay €42.18[5]. Consequently, passengers on short and long-distance flights contribute the vast majority of tax revenues from AT. The average passenger departing from a German airport faced a tax increase of €12.26[6].

The introduction of AT was justified as an environmental measure, however, experts believe that the German government's main objective with the tax was to consolidate its budget (see Krenek and Schratzenstaller 2017)[7]. The government's initial expectation was to raise €1 billion annually from AT (Berster et al. 2010, Steppler 2011). Upon the introduction of the tax, some experts warned (see Steppler 2011) that the German AT was likely to have the same adverse effect on passenger numbers that had been experienced following the introduction of the Dutch version of the tax a few years earlier. The AT remains controversial to this day with frequent calls for its abolition by industry participants and policy makers.

Aviation taxes may impact both the supply (airlines' supply of flights, destinations, and frequencies) and the demand (passengers' demand for airline services) side of the aviation industry. On the supply side, upon the implementation of AT, airlines initially decide to what extent they should pass the cost of these taxes to passengers: their choice is whether to keep ticket prices constant (and absorb the tax themselves) or pass on the tax in the form of higher ticket prices. This decision largely depends on market conditions and the type of strategy

[4] See German Aviation Tax Act 2011 and Deutsche Bundesregierung (2012).
[5] Unfortunately no data are available to estimate these numbers for all of our sample years. The estimation above is based on 2008 data from Berster et al. (2010).
[6] This is the weighted average of the unit taxes considering the shares of passengers traveling under each distance band.
[7] In the German Aviation Tax Act 2011, it is stated that AT should "*provide an incentive for behaviour which is more appropriate to the needs of the environment*".

airlines employ (Zuidberg 2015): profit-maximising airlines are more likely to pass taxes on in comparison with growth-maximizing airlines (these will likely absorb the tax to maintain traffic).

Airlines might also adjust their networks in response to the introduction of aviation taxes. They might choose to serve different airports and provide lower flight frequencies at certain airports (Zuidberg 2015). These adjustments are more likely to be made by low-cost airlines as these airlines are more flexible, and can move airports at relative ease in comparison to traditional carrier airlines as their operations are not tied to large hub airports (Thelle and la Cour Sonne 2017). For this reason, in the case of the German AT, *ceteris paribus*, we should expect larger responses to aviation taxes at smaller regional airports that predominantly serve low-cost airlines than at large hubs. According to Zuidberg (2015) after the implementation of the German AT, the low-cost carrier Ryanair announced that it would cut capacity at a number of German regional airports (for example Bremen or Frankfurt Hahn) it used for its operations, supply side responses of this kind will likely also impact on passenger demand at these airports.

The network adjustment responses of airlines will be partly in anticipation of (or in response to) changes in passenger demand in response to the tax changes (assuming at least some level of pass-through). Changes in passenger demand in response to AT will largely depend on the price elasticity of demand. Price elasticities for air travel might be highly heterogeneous across consumer groups, airports and types of travel (see for example Brons et al. 2002 or Hofer et al. 2008). Specifically, short-haul and leisure passengers are likely to be more sensitive to price changes than long-haul and business passengers (Brons et al. 2002, Hess and Polak 2005, Morlotti et al. 2017). Short-haul passengers might be more price sensitive due to the ease with which they can substitute to other forms of transportation (cars, railway). Once again, short-haul and leisure passengers are likely to provide a large percentage of the traffic at smaller regional airports, while there should be more long-haul and business passengers at hubs, so we should expect a larger demand side response to AT at small regional airports and a lesser response at hubs.

Another possible substitution response by passengers is to start using nearby airports in bordering countries where no aviation tax is in place. In the case of the Dutch AT there is some evidence that the aviation tax prompted Dutch passengers to substitute to nearby German and Belgian airports (Gordijn and Kolkman 2011). It is also likely that airlines respond to this substitution effect by adjusting their network and relocating some services to AT exempt bordering airports. In the German AT case, we would expect that the presence of viable AT exempt airports near the German border (for example Eindhoven, Charleroi, Luxembourg or Basel) would induce a substitution effect (even though Falk and Hagsten (2018) found no significant evidence of this in their analysis). The leakage of air passengers induced by the substitution to bordering airports might also be problematic for governments from a policy perspective: it leads to lower tax revenues but does not significantly reduce the overall number of air passengers, so no improvement in environmental outcomes can be claimed.

3. Data and Identification Strategy

We assess the impact of the German AT on passenger numbers by estimating counterfactual series of passenger numbers for each treated airport – the counterfactual numbers correspond to a scenario where no AT was introduced. The choice of 'treated' airports, for which we believe AT may have had an impact, are German international airports and bordering airports (located outside Germany but within two hours driving time). Our calculations for driving time are based on Google Maps data. Our choice of catchment area is based on the likely cost considerations of passengers: per passenger fuel costs for a two-hour car journey on a motorway near German border regions are similar in value (according to Journey Price Calculator) to the average tax savings from avoiding AT. The choice of catchment area only affects our selection of possible 'treated' bordering airports and has no impact on estimations for other airports. Including bordering airports in the analysis allows us to investigate potential spill-over effects from AT. Treated airports are shown in Figure 1 along with an indication of catchment area, represented by a circle with a radius of 150km (corresponding to approximately two hours of driving time). Blue dots represent airports excluded due to data/model limitations. Our sample includes 21 treated airports in Germany, and 13 treated airports near the German border (but outside of Germany). To assess why AT might have had a different impact at some airports in comparison to others, we estimate separate models for each airport. For treated airports, we compare actual (observed) passenger numbers to counterfactual ones after the introduction of AT to assess the impact of the tax.

3.1 Synthetic control method

To estimate counterfactual passenger numbers, we use the synthetic control method (Abadie et al. 2010, 2015). The synthetic control method constructs counterfactuals (also referred to as synthetic controls) using a weighted average of 'control' airports. Control airports are airports where no changes in AT took place during our sample period[8]. Formally, the synthetic control method as applied to the German AT case can be described as follows.

[8] Information on aviation tax regimes is from EBAA, *A Snapshot of European Aviation Taxes*, September 2015.

Let J be the number of airports in our sample, where $j = 1$ is a specific treated airport. In order to allow for a meaningful comparison, the sample J contains airports similar in characteristics to the treated airport (see Section 3.2 below for more detail).

The airports ($j = 2, \dots, J$) are included in the group of possible control airports. The counterfactual (synthetic control) is a weighted average of control airports and can be represented as a $(Jx1)$ vector of weights $W = (w_2, \dots, w_{J-1})$, where $w_2 + \cdots + w_{J-1} = 1$ and $0 \leq w_j < 1$.

Furthermore, let X_T be a $(kx1)$ vector containing the values of pre-AT characteristics of the treated airport, and let X_C be a (kxJ) matrix containing values for the same characteristics for control airports. These characteristics include predictors of passenger numbers (covariates such as regional purchasing power or flight ticket price inflation) and also pre-AT passenger numbers at airports. We would like to match treated and control airports based on the values of predictors so that our counterfactual best resembles the treated airport in terms of pre-AT characteristics. The difference in pre-AT characteristics between the treated airport and the counterfactual is equal to $X_T - X_C W$. The optimal counterfactual W^* (a weighted average of control airports) selected through the synthetic control procedure is the one that minimises the size of this difference.

Applying W^* to post-AT passenger numbers then gives the counterfactual passenger number $P_C W^*$, which is equal to passenger numbers at selected control airports multiplied by their optimal weights. The effect of AT on passenger numbers at the treated airport is then given by $P_T - P_C W^*$, that is, the post-AT difference between actual passenger numbers at the treated airport (P_T) and counterfactual estimates ($P_C W^*$).

In summary, the synthetic control method chooses control weights so that pre-AT passenger numbers and covariate (predictors) values for the counterfactual are similar (on average) to those at the treated airport. The covariates also control for variation arising from other factors that affect passenger numbers (regional and macroeconomic variables). The synthetic control approach therefore optimises the selection of control airports: to construct counterfactual passenger numbers the procedure finds the convex combination of control airports that provide the 'best fit', that is, the fit between passenger numbers at treated airports and their synthetic control, pre-AT.

As mentioned above, in this paper we construct counterfactuals using separate synthetic control estimations for each treated airport[9]. For these airports, we then compare actual passenger numbers to counterfactual ones after the introduction of AT to assess the impact of the tax.

According to Abadie et al. (2015) synthetic control should be used only when there is a sufficiently large number of pre-treatment periods for the optimisation of the control unit selection. While the number of pre-treatment periods we have in our analysis (eight) is certainly not large, there is no precise recommendation for the number of pre-treatment periods, and several recent examples of research using synthetic control used fewer pre-treatment periods (for example Munasib and Richman 2014, Zhang et al. 2016, or Chamon et al. 2017) [10].

The synthetic control approach is similar to the panel diff-in-diff methodology often used for policy evaluations and also employed in Falk and Hagsten (2018) for their analysis of the impact of Austrian and German AT. We believe however that the synthetic control approach has some notable advantages over panel-diff-in-diff in the context of the present analysis.

First, synthetic control relies on considerably weaker identifying assumptions in comparison to panel diff-in-diff methods (Billmeier and Nannicini 2013). In particular, panel diff-in-diff estimations rely on the assumption of parallel trends in outcomes for treated and control units. In our example, under this assumption, passenger numbers at treated (taxed) airports would have to follow the same pre-AT trends as control (untaxed) airports - post-AT differences in passenger numbers could then be contributed to the presence of AT. For the German AT case, this assumption is difficult to validate due to the high degree of heterogeneity in passenger trends across different airports: passenger numbers are determined by a number of factors and conditions (see Hess and Polak 2005) and it might not be safe to assume that all differences (even conditional on covariates) between treated and control airports are a result of tax changes. On the other hand, synthetic control does not rely on the assumption of parallel trends as it optimises control airport selection on the basis of pre-AT fit in passenger trends between treated and control airports.

[9] Synthetic control estimations in this paper are implemented using the ‘synth’ package in Stata.
[10] We are unable to use earlier data on our sample airports as passenger data are not consistently available before 2003. For example, Eurostat only has data on passenger numbers at German airports from 2003 onwards.

Another advantage of synthetic control in comparison to panel diff-in-diff is that it can account for the presence of time-varying unobservable confounders (Billmeier and Nannicini 2013). This provides a good way to minimise the possibility of omitted variable bias and control for the fact that some shocks (captured by our covariates) to passenger numbers might not occur until after the introduction of AT.

There are limitations to the synthetic control approach that must be considered when applying this method. First, synthetic control relies on balanced panel data, as the process of estimating the counterfactual requires units to be observed in all time periods (Abadie et al. 2015). In the context of this paper, this data requirement is met as we use time-series data on passenger numbers from a balanced panel of European airports in our empirical analysis below. Second, synthetic control estimates may be biased by idiosyncratic shocks to the outcome variable that control units and covariates are unable to capture (Abadie et al. 2015). In the case of German AT, estimates may be biased due to idiosyncratic country, or airport, specific shocks to passenger numbers at German airports. Examples of such shocks to passenger numbers could include terrorist attacks, natural disasters and/or major sporting events. In the context of this paper, a notable concern is that the impact of the 2006 FIFA World Cup, and particularly its final in Berlin, on passenger numbers might interfere with our counterfactual estimations. To ensure that we do not draw conclusions based on biased estimates, we check the validity of our counterfactuals through several sensitivity checks which are presented in Section 4 below. Finally, another limitation of the synthetic control approach is that it does not allow for large-sample asymptotic inference of estimates (Billmeier and Nannicini 2013). Nonetheless, inferences can be made using placebo and robustness tests (Abadie et al. 2010) which are reported in Section 4 of this paper.

3.2 Control airport selection

As mentioned in Section 3.1, we estimate separate synthetic control models for each treated airport. This is done in order to 1) optimise counterfactual estimations for treated airports through the selection of appropriate controls and 2) to assess the heterogeneity of AT impacts at different airports. In order to avoid overfitting (see Abadie et al. 2015), a different set of possible control airports is selected for each treated airport. Overfitting can occur when the control group contains airports that are dissimilar to the treated airport in their main characteristics and the counterfactual estimation is optimised based on artificially matched airports as a result of idiosyncratic variation in passenger numbers.

Criteria employed in selecting control airports include: located in a country with no change in AT over the period; but otherwise similar characteristics to the specific treated airport. Similarity is considered in terms of passenger numbers at treated and control airports. An airport is not included in the possible control group of a treated airport if maximum passenger numbers (over the pre-AT period) at the treated airport were at least twice as large (or half as large) as those at the given control airport. Full details on treated airports and their controls are provided in the Appendix, along with the selected weighted averages used in order to create counterfactual passenger number series.

Following Billmeier and Nannicini (2013), two sets of estimates are constructed for each treated airport: set A use control airports from countries surrounding Germany under the assumption that treated and control units are likely to face similar macroeconomic and regional shocks; while set B use a larger number of control airports from across the European Economic Area (EEA). The preferred results are those from whichever set of estimates provides the best fit for the pre-tax period (as in Ormaechea et al. 2017).

3.3 Covariate selection

In our analysis, we include a number of covariates to control for factors affecting passenger trends at airports. The covariates included are: purchasing power per capita in euros (in constant prices) at the NUTS2 regional level, to control for the impact of macroeconomic shocks; lagged passenger numbers, to capture airport specific trends; and flight ticket price inflation in the country of the airport, to control for changes in ticket prices on the aggregate level. First-differences are also used to control for airport fixed effects. Annual data on passenger numbers using each airport over the period 2003-2015 are from Eurostat[11]. Data on purchasing power per capita, and flight ticket price inflation are also from Eurostat.

3.4 Data restrictions

To avoid biased estimates, we need to make restrictions to our data. Estimation bias could arise from including treated airports in the group of possible controls: under such circumstances counterfactual passenger numbers might also be affected by AT changes. Austrian airports are therefore excluded from the group of possible control airports, since Austria also introduced an AT in 2011. Furthermore, contrary to Falk and Hagsten (2018), we do not 'treat' Austrian airports and investigate their AT's impact on passenger numbers. This is because the Austrian AT charged different rates from the German version of the tax – our preference is to keep the treatment homogenous so that we can assess the heterogeneity of treatment effects across airports and relate these differences to airport characteristics.

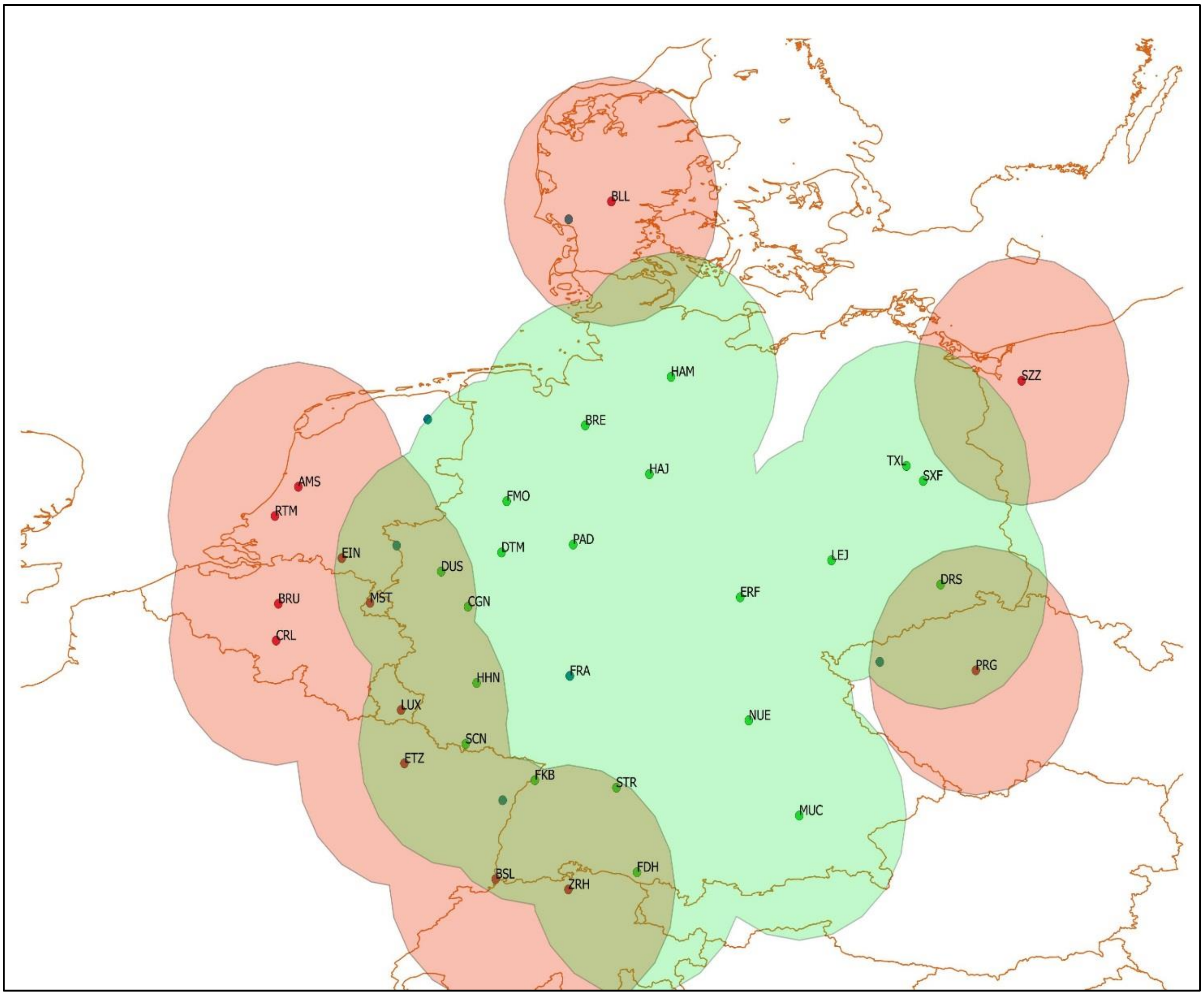
In addition, the Netherlands introduced an AT in July 2008 but abolished it a year later. It is possible that some of the longer-term effects (see Zuidberg 2015) of the abolition of Dutch AT will coincide with the introduction of the German aviation tax – this is a limitation of our analysis[12]. Nonetheless, we do not exclude Dutch airports from the group of treated airports as they provide some of the best substitution opportunities for German passengers after the introduction of AT – if we observe substitution effects after AT these are likely to concern Dutch airports close to the German border. Furthermore, German AT was introduced more

[11] These data concern both departing, arriving and transfer passengers, which is a limitation since that the tax is charged on departing passengers.

[12] This is a limitation for the estimations that concern Dutch airports. As Dutch airports are 'treated' and are therefore not in the control groups of other airports, estimations for other airports are unaffected by our decision to include them in the sample.

than a year after the abolition of Dutch AT, our estimations therefore likely capture most of the impact of the abolition on passenger numbers during this period.

Figure 1. Map of Airports and Catchment Areas



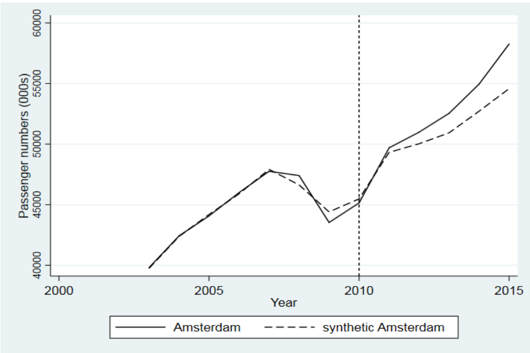
Note: German airports and catchment areas are shown in green; bordering airports/catchment areas in red; and points with no label indicate airports excluded from estimation. Information on airport codes can be found in Tables 2-3 in the Appendix.

4. Results

The full synthetic control results are provided in the Appendix. Here we show results for two airports by way of examples. Figures 2 and 3 plot actual and counterfactual (synthetic) passenger numbers for Amsterdam and Nuremberg respectively. The impact associated with the introduction of AT corresponds to the vertical difference (gap) between the actual and counterfactual time trends after 2010. The imposition of AT in 2011 is associated with increased passenger numbers relative to the counterfactual in the case of Amsterdam, and decreased numbers in the case of Nuremberg.

Figures 2-3: Examples of Synthetic Control Estimates

Amsterdam



Nuremberg

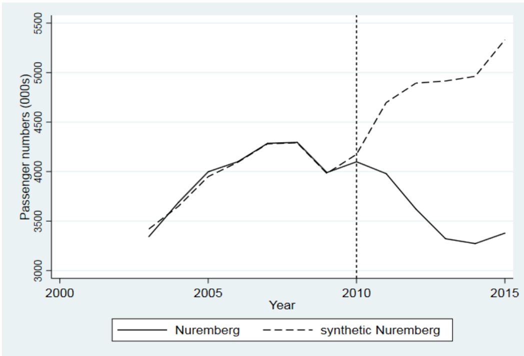
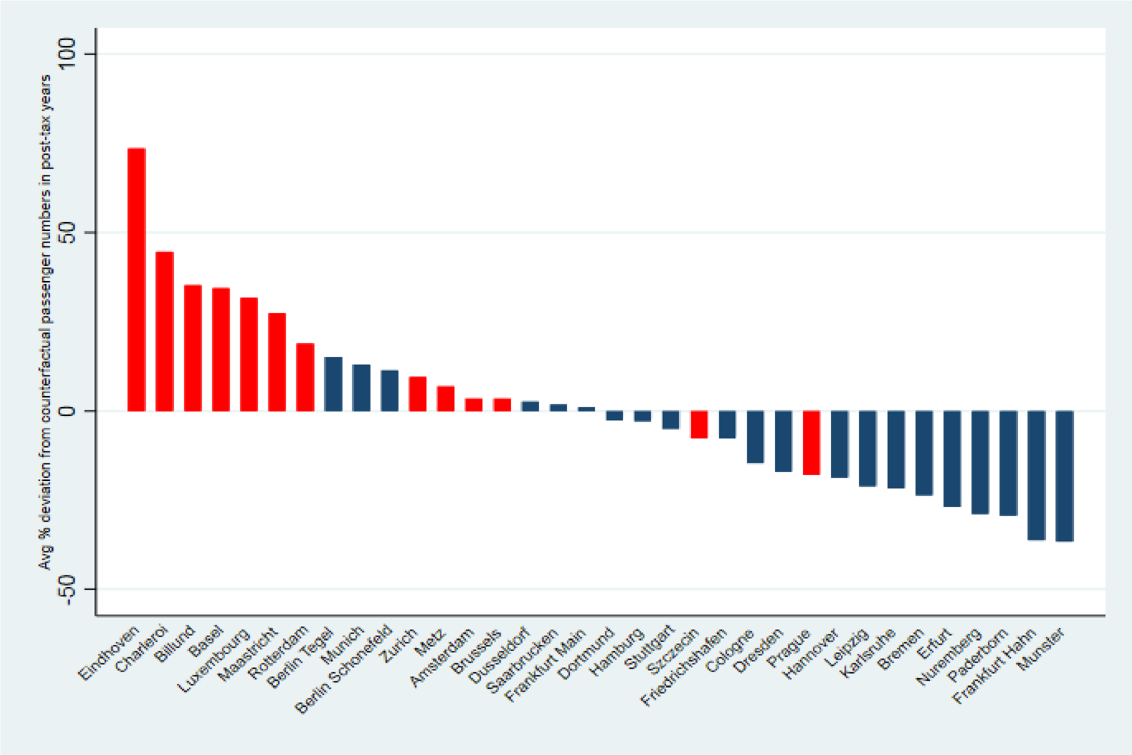


Figure 4 summarises the full set of results for the treated airports, by plotting the post-tax percentage deviations of actual passenger numbers as compared to the counterfactual. The plotted figures are each airport's average percentage change in passenger numbers over the post-tax sample, i.e. 2011-2015, in each case.

Recall from Section 2 that different airport types (specifically hubs as distinct from regional airports) might respond differently to the implementation of AT. For this reason, Figure 5 provides a summary of the results grouped by (treated) airport type. Airports are designated as hubs based on their size and the airlines that use them as the centre for their operations and networks: the four largest German airports (Frankfurt Main, Munich, Berlin-Tegel and Dusseldorf) are obvious choices as they handle a significantly larger number of passengers in comparison to other airports and also serve as the hubs of a number of airlines. We include Hamburg Airport in the hub category as it serves a considerably larger number of passengers in comparison to the next busiest German airport (Cologne). All non-hub airports in Germany are in the regional airports group, while bordering airports are in a separate group regardless of their size. Finally, we create a separate 'low-cost' airport group to assess whether airports serving predominantly low-cost airlines were impacted differently by the AT introduction. Low-cost airports are those airports where at least 50% of the services are provided by low-cost airlines[13]. This category contains almost all German non-hub airports, with the exception of Stuttgart.

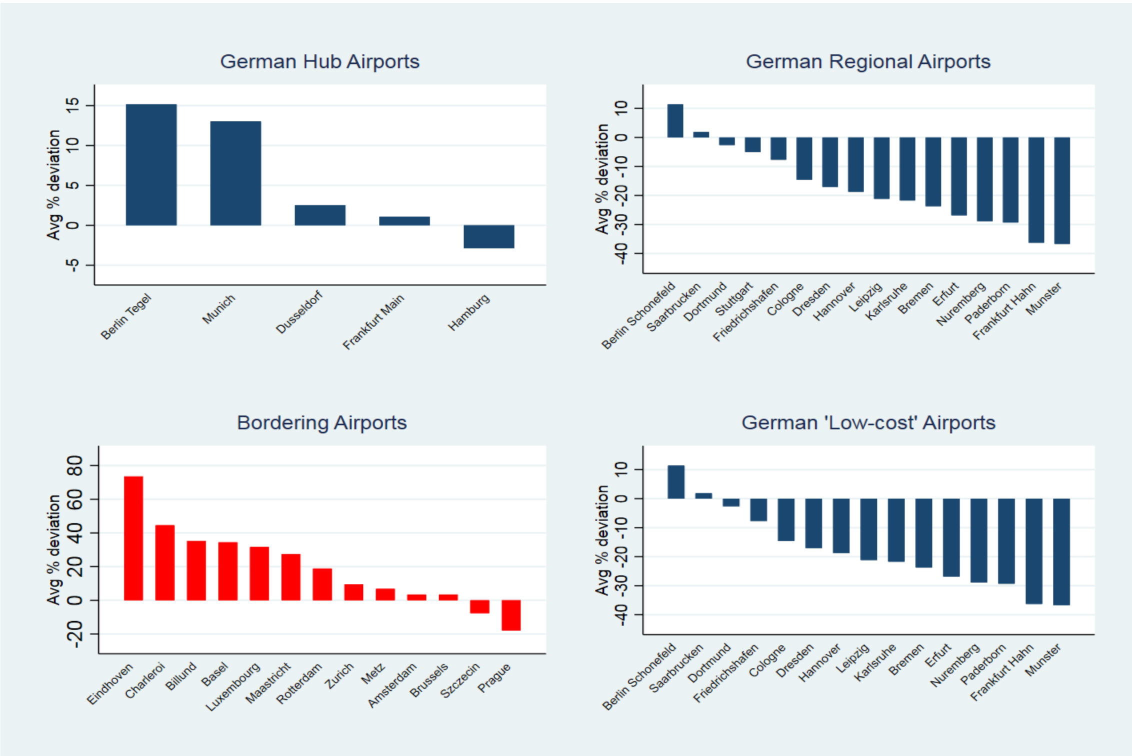
[13] Information on services is collected from airport websites. This information is not available for previous years so 2018 data are used.

Figure 4. Post-Tax Deviations from Counterfactual Passenger Numbers (Treated Airports)



Bordering airports are marked red.

Figure 5. Post-Tax Deviations from Counterfactual Passenger Numbers – by Airport Type



Most German airports appear on the right of the Figure 4, indicating estimated losses of passengers since AT's introduction. Most bordering airports, shown in red, made gains. A small number of German airports, notably Berlin Tegel, Dusseldorf and Munich saw gains in passenger numbers relative to the no tax counterfactual. In Figure 5, it is also clear that most regional airports in Germany (most of these airports serving low-cost airlines) lost passengers (in comparison the counterfactual scenario) since the introduction of AT.

Aggregating the results shown in Figure 4 for German airports provides us with an estimate of 4 million passengers lost (annually) compared to the counterfactual scenario under the assumption of no AT. This is roughly 2% of annual passenger numbers at these airports so indicates rather a small aggregate (net) effect on passenger demand at German airports.

4.1 On the plausibility of the findings

To check the plausibility of our findings we: provide information on pre-AT fit of models; explore the sensitivity of results to the choice of control airports; and provide information on the significance of our estimates based on placebo tests.

The fit of synthetic control models in the pre-AT period is measured using Root Mean Squared Prediction Errors (RMSPE) - constructed from the squared difference between actual and counterfactual passenger numbers for each pre-AT year, averaged across the available pre-tax years. The normalised RMSPE adjusts for airport size so is expressed as a % of that airport's passenger numbers in 2010; a figure in excess of 5% is indicative of poor fit and signals that estimates of the impact of AT must then be treated with caution.

The check on the sensitivity of results considers whether estimated impacts of AT are affected by the inclusion/exclusion of particular airports in the set of controls. Recall from Section 3.2, that we estimated separate synthetic control models for each treated airport using different sets of control airports (set A and set B)[14]. Similar estimated impacts from the two sets are indicative of robustness (see Table 1, column 2).

Asymptotic inference is not possible using the synthetic control method. Inference on significance of estimated effects therefore comes from placebo tests, following Abadie et al. (2010). First the AT treatment is assigned to each control airport and impacts estimated. Since no AT was actually introduced for these airports we expect any estimated impacts to be small and random. Essentially, we have confidence in our results for treated airports if their estimated post-tax gaps are large relative to those generated in the placebo tests[15].

To evaluate this, we use RMSPE ratios to construct p-values. RMSPE ratios are measured as the post-tax gap (between actual and counterfactual passenger numbers) divided by the pre-tax gap. These ratios indicate the extent to which post-tax gaps are large in comparison to the pre-tax fit of our counterfactuals. Each p-value then indicates the likelihood that a randomly selected RMSPE ratio from the sample of placebo tests is larger than that of the given treated airport. It is simply the number of RMSPE ratios from the placebo group that exceed the ratio for the treated airport, and divided by the number of control airports in the group. For

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[14] The synthetic control results presented in the Appendix show estimates from the set of controls that provides the better pre-AT fit. Figures showing results for estimations using the other set of control variables can be found in the Online Appendix (https://sites.google.com/view/danielborbely/research).
[15] Graphical representations of the placebo tests for each treated airport can be found in the Online Appendix.

example, if the treated airport's RMSPE ratio is larger than the ratio for all of its control airports (say there are 50 of them), the p-value is going to be equal to 0/50 = 0.

Significance can be interpreted as indicating that AT had an unusually large effect on a treated airport relative to the placebo effects for control airports. Recall though that inference must be predicated on well-fitting models that are reasonably robust to the choice of controls. Table 1 summarises our findings.

Most of our airport estimates are based on synthetic control models that achieve a good fit prior to the introduction of AT and are robust. Some of these results are not significant however. This is likely a consequence of relatively small effects associated with AT at these airports (for example Frankfurt Main), or large idiosyncratic effects coinciding with AT at some of the control airports. As the results for these treated airports are robust and are based on reliable counterfactual estimations (good pre-AT fit), we should not reject them despite the lack of significance.

In Table 1, airport results marked with shaded rows are based on ill-fitting synthetic control models. Counterfactual estimations for these airports are unreliable as counterfactual passenger numbers already substantially deviate from actual numbers before the introduction of AT. The small number of airports falling under this category tend to be small regional airports, with low annual passenger numbers. It is possible that passenger number changes at these airports are too idiosyncratic to be modelled appropriately. Since these airports serve very few airlines and destinations, a single airline changing routes or schedules might have a substantial impact on passenger numbers.

Table 1. Summary of Robustness/Inference Measures:

Airports	**Pre-estimation error (% of passengers)**	**Sample Robustness Check**	**RMSPE Ratio**	**p-value**
		German hubs		
Berlin Tegel	3.60	✓	4.61	0.273
Dusseldorf	1.49	✓	2.92	0.700
Frankfurt Main	0.53	✓	2.17	0.818
Hamburg	1.62	✓	4.16	0.706
Munich	0.53	✓	24.56	0.000***
		German regional airports		
Berlin Schonefeld	5.89	✓	1.75	0.682
Bremen	2.44	✓	12.91	0.032**
Cologne	0.61	✓	27.17	0.000***
Dortmund	3.65	✓	1.45	0.914
Dresden	0.55	✓	37.49	0.000***
Erfurt	16.68	✓	1.58	0.726
Frankfurt Hahn	4.11	✓	11.23	0.076*
Friedrichshafen	2.07	✓	3.71	0.313
Hannover	4.00	✓	6.17	0.238
Karlsruhe	5.83	✓	4.55	0.600
Leipzig	2.62	✓	9.07	0.152
Munster	1.33	✓	33.15	0.000***
Nuremberg	0.81	✓	43.62	0.000***
Paderborn	6.02	✓	5.95	0.393
Saarbrucken	7.88	✓	1.26	0.813
Stuttgart	1.37	✓	4.19	0.474
		Bordering airports		
Amsterdam	0.68	✓	22.13	0.000***
Basel	3.93	✓	10.36	0.038**
Billund	3.41	✓	8.32	0.111
Brussels	1.53	✓	4.26	0.818
Charleroi	6.59	✓	4.49	0.300
Eindhoven	4.77	✓	169.09	0.000***
Luxembourg	2.80	✓	11.71	0.057*
Maastricht	18.32	✓	1.97	0.643
Metz	5.32	✓	1.48	0.867
Prague	1.99	✓	10.76	0.143
Rotterdam	8.71	✓	2.91	0.733
Szczecin	10.71	✓	1.52	0.714
Zurich	3.02	✓	3.06	0.636

Note: ***Significant at 1% level, **5%, *10%. The synthetic control model for a given airport is considered ill-fitting (marked with the shaded rows) when pre-estimation error (RMSPE) is higher than 5% of passenger numbers in 2010. The sample robustness check relies on the comparison of estimates that use different samples of control airports (see Section 4.1).

5. Discussion

The findings set out in Section 4 are consistent with the likely behavioural responses of agents to increases in AT.

a) That bordering airports are estimated to have benefited from AT is consistent with passengers substituting to alternative airports to avoid ticket prices that incorporate AT. Such effects will be strongest when German and non-German airport catchment areas overlap (for example in the case of Eindhoven – EIN or Basel - BSL, see Figure 1). Our findings of sizable substitution effects at most bordering airports contrast with Falk and Hagsten (2018), who find no significant impact on bordering airports from German and Austrian AT using a panel diff-in-diff approach. It is possible that differences in results arise from methodological differences: while our approach allows us to observe airport-specific treatment effects at each bordering airport, in Falk and Hagsten (2018) bordering airports are pooled together in the panel diff-in-diff analysis potentially allowing outlier airports (where AT had no effect or a negative effect) to put a downward bias on the overall treatment effect. Outliers are also present in our sample: in the case of two bordering airports (Szczecin and Prague) decreased passenger numbers can be associated with the introduction of AT. A likely explanation for the lack of a substitution towards these airports is that, for one reason or another, they do not offer a viable alternative to nearby German airports: for example, road or rail links from Germany to these airports might not be appropriate; or the airports offer different services to German counterparts. Nonetheless, the large negative impact observed for Prague Airport is difficult to explain and is likely a consequence of some exogenous shock to passenger numbers we could not account for in our synthetic control estimations.
b) It is possible that the response of airlines, especially low-cost ones, have exacerbated the impact of AT on passenger numbers. Anecdotal evidence from the Dutch and German AT cases point to some airlines having responded to an anticipated drop in demand by relocating their services to airports outside the AT area (Zuidberg 2015). As mentioned in Section 2, such responses ought to be strongest among budget airlines, since they are less tied to hubs and able to relocate quickly. Of course, the elimination of some destinations from regional airports forces travellers to shift their custom elsewhere. Our estimates are consistent with these explanations: smaller,

regional airports (predominantly serving low-cost airlines) lost proportionately more passengers after the introduction of AT (see Figure 5). In fact, nearly all airports shown on the right side of Figure 4 - airports with the largest losses in passenger numbers from AT - fall under this category[16]. In this respect our findings are in line with those of Falk and Hagsten (2018).

c) Estimates for hub airports within Germany either show small negative effects (Hamburg) or positive impacts of AT (Berlin Tegel, Dusseldorf, Frankfurt Main and Munich). The greater resilience of passenger numbers at airline hubs facing AT is consistent with a lower price elasticity of demand. A likely explanation is that hubs attract a greater proportion of passengers flying on business trips, see Hess and Polak (2005); greater proportion of untaxed transfer passengers; fewer offerings from budget airlines; fewer opportunities to substitute to non-taxed routes, and a greater attachment of non-budget airlines to particular hubs (which reduces the supply side response). It is also possible that hubs within Germany gain passengers who substitute away from budget airlines once the latter airlines reduce their flights from German regional airports and from substitution induced by the relatively larger proportionate change in budget airline's ticket prices (assuming pass-on), since the AT due varies only by distance, not by service level.

d) While our analysis does not explicitly focus on policy outcomes, it is possible to draw some policy implications from our results. Recall from Section 1 that the main objectives of governments who implement ATs are: 1) to reduce the environmental burden of the aviation industry and 2) revenue raising.

   From an environmental perspective, the reduction in air travel demand in Germany could act to reduce pollution levels, however the fact that some of the demand relocates to bordering airports mitigates the potential for an overall reduction in pollution levels. It is also possible that the observed changes in travel demand at hubs vs regional airports will lead to a larger share of passengers taking long-haul flights which results in greater pollution (see Mayor and Tol 2007). The cross-border substitution effect found in our analysis also provides evidence in support of the argument that, in order to successfully curb emissions from air travel, a harmonised EU-wide aviation tax is needed (Krenek and Schratzenstaller 2017). As long as AT

[16] Results for the two outliers, namely Berlin Schonefeld and Saarbrucken are based on ill-fitting synthetic control models.

rates are allowed to vary between neighbouring countries, tax avoidance through cross-border substitution will remain a salient option for mobile passengers, leading only to a relocation of air travel demand and a reduction in the intended positive environmental impact of aviation taxes (Leicester and O'Dea 2008).

From a tax-revenue perspective, the substitution effect observed at bordering airports leads to lost tax revenues as passengers substitute to airports where they can avoid paying AT. In Section 4, we estimated that 4 million passengers were lost annually for German airports; assuming that half of these were departing (taxed) passengers and multiplying with the estimated average unit tax of €12.26, we estimate the annual loss in tax revenues to be approximately €24.52 million, or 2.45 percent of expected government revenues from AT (see Section 2). On the other hand, increased traffic at hub airports, with a higher share of business/long-haul passengers paying higher rates of AT, likely has a positive impact on average tax paid and consequently on tax revenues. Overall, the German airports included in our sample had roughly 203.9 million annual passengers combined in the post-AT years (on average); if half of these passengers were taxed, estimated tax revenues from AT amount to approximately €1.25 billion annually, slightly exceeding the policy target set by the German government.

Regardless, considering the dual objectives of the policy, in an ideal scenario AT should curb overall air travel demand (to reduce emissions), without a cross-border substitution effect that results in the loss of the tax base. Our results provide evidence to the contrary: German demand, and overall air travel demand, is not reduced to a large extent, but the cross-border effect is substantial. Please note, however, that our tax revenue estimations are based on back-of-the-envelope type calculations, as information on the number of departing passengers (the composition of the tax base) in each AT band is not available for the purposes of this research. To appropriately assess the impact of behavioural responses on policy outcomes, further analysis is needed at a more disaggregated level.

6. Conclusions

The synthetic control approach has provided estimates of the effects of German AT on passenger numbers using German airports and airports outside Germany but near the border. Estimates indicate that AT has significantly reduced passenger numbers, relative to the counterfactual of zero AT, for many German airports, though passenger numbers tended to hold up at and even grow somewhat at some hub airports. At the same time, most bordering airports gained passenger numbers. These findings are consistent with likely and mutually reinforcing behavioural responses of passengers and airlines to AT and the induced changes in the relative prices of airline services. From a policy perspective, these behavioural responses can have ambiguous impacts on both the environmental and revenue-raising objectives associated with AT. This paper also provides a methodological contribution to the literature on aviation taxes: future research on aviation taxes, for example studies focusing on the ATs recently introduced in Norway and Sweden, could make use of the synthetic control approach to estimate the impact of these taxes on a variety of outcomes.

Our analysis has a number of notable limitations. In our estimations, we are unable to explicitly model the impacts of substitute forms of transportation on German (and bordering) airports[17]. For example, the deregulation of long-distance bus services in Germany in 2013 has led to a large increase in intra-urban bus traffic within the country (Knorr and Lueg-Arndt 2016). It is possible that this had an effect on passenger numbers at some of the regional airports that offer domestic flights. In addition, we do not model tourism related factors that might drive (inbound) demand for air travel. For example, Germany reduced the VAT on hotel accommodation from 19% to 7% in 2010 (see European Commission, VAT database) which might have had a positive impact on the demand for inbound air travel. Finally, an additional limitation is that the use of aggregate data does not allow us to distinguish between the behavioural responses of different passenger types (leisure/business, short-haul/long-haul) and prohibits the estimation of tax revenues from AT. Future research, using more detailed micro-data on passengers, is needed to disentangle behavioural responses and provide an accurate assessment of tax revenue considerations.

[17] For example, there does not seem to be consistent data available on the number of bus passengers in European countries over our sample period. Eurostat has data on this for some countries but not others (German data are not available).

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References

Abadie, A., Diamond, A. and Hainmueller, J., 2010. Synthetic control methods for comparative case studies: Estimating the effect of California's tobacco control program. *Journal of the American Statistical Association*, *105*(490), pp.493-505.

Abadie, A., Diamond, A. and Hainmueller, J., 2015. Comparative politics and the synthetic control method. *American Journal of Political Science*, *59*(2), pp.495-510.

Asplund, M., Friberg, R. and Wilander, F., 2007. Demand and distance: evidence on cross-border shopping. *Journal of Public Economics*, *91*(1-2), pp.141-157.

Berster, P., Gelhausen, M., Grimme, W., Keimel, H., Maertens, S., Pabst, H. and Wilken, D., 2010. The impacts of the planned air passenger duty in Germany. In *Infraday conference*. TU Berlin.

Billmeier, A. and Nannicini, T., 2013. Assessing economic liberalization episodes: A synthetic control approach. *Review of Economics and Statistics*, *95*(3), pp.983-1001.

Brons, M., Pels, E., Nijkamp, P. and Rietveld, P., 2002. Price elasticities of demand for passenger air travel: a meta-analysis. *Journal of Air Transport Management*, *8*(3), pp.165-175.

Chamon, M., Garcia, M. and Souza, L., 2017. FX interventions in Brazil: a synthetic control approach. *Journal of International Economics*, *108*, pp.157-168.

Deutsche Bundesregierung. 2012. *Bericht an den Deutschen Bundestag uber die Auswirgunken der Einfuhrung des Luftverkehnrsteuergesetzes auf den Luftverkehrssektor und die Entwicklung der Steuereinnahmen aus der Luftverkehrsteuer.* Berlin.

Edinburgh Airport, 2015. The impact of reducing APD on Scotland’s airports.

Falk, M. and Hagsten, E., 2018. Short-run impact of the flight departure tax on air travel. *International Journal of Tourism Research*.

Forsyth, P., Dwyer, L., Spurr, R. and Pham, T., 2014. The impacts of Australia's departure tax: Tourism versus the economy?. *Tourism Management*, *40*, pp.126-136.

Gordijn, H. and Kolkman, J., 2011. Effects of the Air Passenger Tax: Behavioral responses of passengers, airlines and airports. *KiM Netherlands Institute for Transport Policy Analysis: Ministry of Infrastructure and the Environment*.

Graham, A., 2000. Demand for leisure air travel and limits to growth. *Journal of Air Transport Management*, *6*(2), pp.109-118.

Hess, S. and Polak, J.W., 2005. Mixed logit modelling of airport choice in multi-airport regions. *Journal of Air Transport Management*, *11*(2), pp.59-68.

Hofer, C., Windle, R.J. and Dresner, M.E., 2008. Price premiums and low cost carrier competition. *Transportation Research Part E: Logistics and Transportation Review*, *44*(5), pp.864-882.

Jankiewicz, J. and Huderek-Glapska, S., 2016. The air transport market in Central and Eastern Europe after a decade of liberalisation–Different paths of growth. *Journal of Transport Geography*, *50*, pp.45-56.

Joossens, L. and Raw, M., 1995. Smuggling and cross border shopping of tobacco in Europe. *BMJ: British Medical Journal*, *310*(6991), p.1393.

Knorr, A. and Lueg-Arndt, A., 2016. Intercity bus deregulation in Germany–Intramodal and intermodal effects after two years. *Research in Transportation Economics*, *59*, pp.323-329.

Krenek, A. and Schratzenstaller, M., 2017. Sustainability-oriented tax-based own resources for the European Union: a European carbon-based flight ticket tax. *Empirica*, *44*(4), pp.665-686.

Leicester, A. and O'Dea, C., 2008. Aviation taxes. *The IFS Green Budget 2008*, pp.187-211.

Mayor, K. and Tol, R.S., 2007. The impact of the UK aviation tax on carbon dioxide emissions and visitor numbers. *Transport Policy*, *14*(6), pp.507-513.

Mayor, K. and Tol, R.S., 2010. The impact of European climate change regulations on international tourist markets. *Transportation Research Part D: Transport and Environment*, *15*(1), pp.26-36.

Morlotti, C., Cattaneo, M., Malighetti, P. and Redondi, R., 2017. Multi-dimensional price elasticity for leisure and business destinations in the low-cost air transport market: Evidence from easyJet. *Tourism Management*, *61*, pp.23-34.

Munasib, A. and Rickman, D.S., 2015. Regional economic impacts of the shale gas and tight oil boom: A synthetic control analysis. *Regional Science and Urban Economics*, *50*, pp.1-17.

Nielsen, S.B., 2001. A simple model of commodity taxation and cross-border shopping. *Scandinavian Journal of Economics*, *103*(4), pp.599-623.

Ormaechea, S.A., Komatsuzaki, T., Correa-Caro, C., 2017. Fiscal Reforms, Long-term Growth and Income Inequality, *IMF Working Papers*

Pels, E., Nijkamp, P. and Rietveld, P., 1998. *Equilibrium airfares, frequencies and airport taxes in a multiple airport region: An application of the nested logit demand model* (No. 98-073/3). Tinbergen Institute Discussion Paper.

Seetaram, N., Song, H. and Page, S.J., 2014. Air passenger duty and outbound tourism demand from the United Kingdom. *Journal of Travel Research*, *53*(4), pp.476-487.

Steppler, U., 2011. German air travel tax and other duties: A new European trend?. *The Air and Space Lawyer*, *24*(1), p.1.

Steverink, B. and van Daalen, C.E., 2011, March. The Dutch Taxation on Airline Tickets. In *the 29th international conference of the System Dynamics Society*.

Thelle, M.H. and la Cour Sonne, M., 2017. Airport competition in Europe. *Journal of Air Transport Management*.

Valdes, V., 2015. Determinants of air travel demand in Middle Income Countries. *Journal of Air Transport Management*, *42*, pp.75-84.

Zhang, Y., Palma, M.A. and Xu, Z.P., 2016. Unintended effects of the Alabama HB 56 immigration law on crime: A preliminary analysis. *Economics Letters*, *147*, pp.68-71.

Zuidberg, J., 2015. The implications of air travel taxes. *Journal of Airport Management*, *10*(1), pp.64-72.

Web Sources

FCC Aviation 2011, accessed May 2019 <http://www.fccaviation.com/downloads/aviation-tax-act-annex-1.pdf>

FCC Aviation 2011, accessed May 2019 <http://www.fccaviation.com/downloads/aviation-tax-act-annex-2.pdf>

FCC Aviation 2011, accessed May 2019 <http://www.fccaviation.com/downloads/aviation-tax-act.pdf>

FCC Aviation 2011, accessed May 2019 < https://www.fccaviation.com/downloads/guidelines-german-aviation-tax.pdf>

DW, *German Air Passenger Tax Under Increased Fire*, August 2017, accessed May 2019 <http://www.dw.com/en/german-air-passenger-tax-under-increased-fire/a-40168081>

EBAA, *A Snapshot of European Aviation Taxes*, September 2015, accessed May 2019 <https://www.ebaa.org/european-affairs/taxes-aviation-taxes-europe>

Eurostat, Database, accessed October 2017 <http://ec.europa.eu/eurostat/data/database>

European Commission, Tax Database, accessed May 2019 <http://ec.europa.eu/taxation_customs/tedb/taxSearch.html>

Journey Price Calculator, accessed October 2017 <https://journeyprice.co.uk/>

Google Maps, accessed October 2017 <https://www.google.com/maps>

Appendix

Table 1. Descriptive Statistics

Variable	**Mean**	**St. Dev**	**Min**	**Max**
Passenger numbers (000s)	6656.043	11954.955	24.65	75017.52
Annual % change in passenger numbers	5.47	18.45	-57.78	226.03
Ln (PP per capita)	10.17	0.381	8.748	11.24
Average annual change in ln (PP)	0.207	0.450	-0.192	0.202
Average annual flight ticket price inflation	1.663	1.432	-1.640	12.06

Table 2. Treated Airports, Control Airports, and Synthetic Control Weights – German Airports

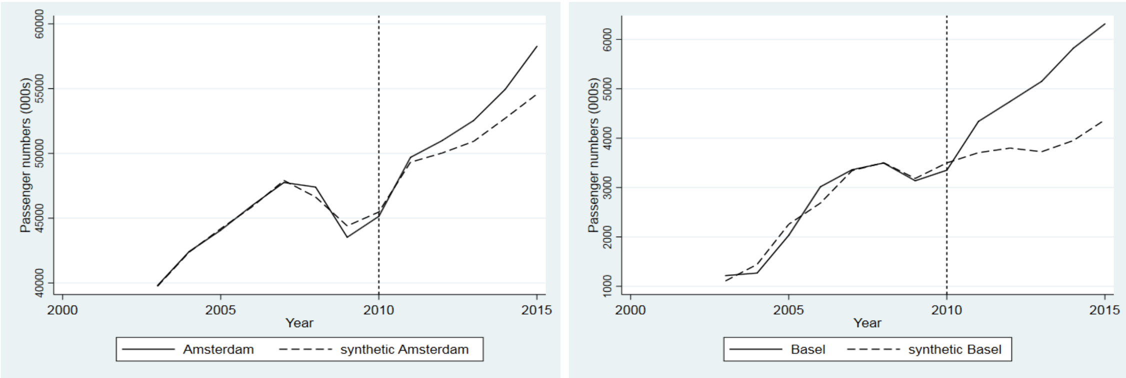
Treated Airport (Airport Code)	**Control Airports (SC weights)**
Nuremberg (NUE)	Bilbao, Bordeaux, Bratislava, Burgas, Chania, Faro, Gdansk, Girona, Goteborg (0.251), Heraklion, Ibiza, Kerkira, Kos, Larnaka, Malmo (0.242), Marseille, Menorca, Nantes (0.027), Pafos, Porto, Riga, Rodos, Santiago, Sevilla (0.035), Sofia, Stockholm, Stockholm B (0.044), Tallin, Thessaloniki, Toulouse (0.332), Valencia (0.068), Vilnius, Wroclaw
Leipzig (LEJ)	Asturias, Bilbao, Bordeaux, Bratislava, Burgas, Chania, Gdansk, Girona, Jerez, Kerkira, Kos, Larnaka, Lille, Ljubljana, Malmo, Menorca, Montpellier, Murcia, Nantes, Pafos, Reus, Riga, Rodos, Santander (0.037), Santiago, Santorini, Sevilla, Sofia, Stockholm, Stockholm B (0.613), Strasbourg, Tallin, Thessaloniki (0.285), Valencia (0.065), Varna, Vilnius, Wroclaw
Munich (MUC)	Barcelona, Copenhagen, Geneva (0.521), London H, Madrid (0.275), Paris Orly, Palma, Paris CDG (0.152), Stockholm Main (0.052)
Frankfurt Main (FRA)	Athens, Barcelona (0.203), Copenhagen, Helsinki, Lisboa, London H (0.606), Madrid, Paris Orly, Palma, Paris CDG (0.071), Stockholm Main (0.12)
Berlin-Tegel (TXL)	Alicante (0.141), Athens, Barcelona, Copenhagen, Geneva, Helsinki, Lisboa (0.781), Nice, Paris Orly (0.079), Palma, Stockholm Main
Cologne (CGN)	Alicante, Athens, Bordeaux, Budapest (0.417), Faro, Goteborg (0.025), Helsinki (0.216), Heraklion, Ibiza, Larnaka, Lyon, Malaga (0.186), Marseille (0.047), Nice (0.096), Porto (0.013), Riga, Thessaloniki, Toulouse (0.001), Valencia
Dortmund (DTM)	Aalborg, Almeria, Asturias, Bastia, Bilbao (0.113), Bratislava (0.177), Burgas, Chania, Coruna, Gdansk, Granada, Jerez, Kerkira, Kos, Lille, Ljubljana, Malmo, Menorca, Montpellier, Murcia (0.391), Nantes, Pafos, Reus, Rodos, Santiago, Santorini, Sofia, Stockholm, Stockholm B, Tallin, Timisoara, Varna, Vigo, Vilnius (0.318)
Hamburg (HAM)	Alicante, Athens, Budapest (0.116), Copenhagen, Geneva, Helsinki (0.72), Lisboa (0.15), Lyon, Malaga, Marseille, Nice, Paris Orly, Palma (0.014), Porto, Stockholm Main
Dusseldorf (DUS)	Athens, Barcelona, Copenhagen, Geneva (0.082), Helsinki, Lisboa (0.603), Malaga, Nice, Paris Orly (0.314), Palma, Stockholm Main
Munster (FMO)	Aalborg, Almeria (0.131), Asturias, Bastia, Biarritz, Bratislava, Burgas, Chania, Coruna, Granada, Jerez, Kerkira, Kos, Lille, Ljubljana (0.199), Malmo (0.23), Menorca (0.07), Montpellier (0.369), Murcia, Pafos, Reus, Santiago, Santorini, Stockholm, Stockholm B, Tallin, Timisoara, Varna, Vigo, Wroclaw
Bremen (BRE)	Aalborg, Almeria, Asturias, Bastia (0.517), Biarritz, Bilbao, Bordeaux, Bratislava, Burgas, Chania, Coruna, Gdansk, Girona, Goteborg, Granada, Heraklion, Ibiza, Jerez, Kerkira, Kos, Larnaka (0.003), Lille, Ljubljana, Malmo, Menorca, Murcia, Nantes, Pafos, Porto (0.407), Reus, Riga, Rodos, Santorini, Sevilla, Sofia, Stockholm B, Tallin, Thessaloniki, Timisoara, Varna, Vigo, Vilnius, Wroclaw (0.073), Zakintos
Frankfurt Hahn (HHN)	Bilbao, Bordeaux, Bratislava, Burgas, Chania, Faro, Gdansk (0.259), Girona, Goteborg, Heraklion (0.208), Ibiza, Kerkira, Kos, Larnaka, Malmo, Menorca, Nantes, Pafos, Porto, Riga (0.053), Rodos (0.267), Santiago, Sevilla, Sofia, Stockholm, Stockholm B, Tallin, Thessaloniki, Toulouse, Valencia (0.212)
Stuttgart (STR)	Alicante, Athens, Bordeaux, Budapest (0.22), Faro, Goteborg (0.212), Helsinki, Heraklion, Ibiza, Larnaka, Lisboa, Lyon, Malaga (0.448), Marseille, Nice, Porto (0.12), Thessaloniki, Toulouse, Valencia
Paderborn (PAD)	Aalborg, Almeria (0.262), Asturias, Bastia, Biarritz, Bratislava, Burgas, Coruna, Granada, Jerez, Kerkira, Kos, Lille, Ljubljana, Malmo, Montpellier (0.61), Murcia, Pafos, Reus, Santiago, Santorini, Stockholm B, Tallin, Timisoara, Varna, Vigo, Wroclaw, Zakintos (0.128), Zaragoza
Berlin Schonefeld (SXF)	Alicante, Bordeaux, Budapest, Faro, Goteborg, Helsinki, Heraklion, Ibiza, Larnaka, Lyon, Malaga, Marseille, Nantes, Nice, Porto (0.311), Riga (0.568), Rodos, Sevilla (0.121), Thessaloniki, Toulouse, Valencia
Dresden (DRS)	Aalborg, Almeria, Asturias, Bastia (0.051), Biarritz, Bratislava, Burgas, Chania, Coruna, Gdansk (0.065), Granada, Jerez, Kerkira, Kos, Lille, Ljubljana, Malmo (0.109), Menorca (0.152), Montpellier, Murcia, Pafos (0.492), Reus, Santiago (0.09), Santorini, Stockholm (0.032), Stockholm B, Tallin, Timisoara, Varna, Vigo, Vilnius (0.009), Wroclaw, Zakintos
Karlsruhe (FKB)	Aalborg, Almeria, Asturias, Bastia, Biarritz, Bratislava, Burgas, Coruna, Granada, Jerez, Kerkira, Kos, Lille, Ljubljana, Malmo, Montpellier, Murcia, Pafos, Reus, Santiago, Santorini, Stockholm B, Tallin, Timisoara, Varna, Vigo, Wroclaw (0.613), Zakintos, Zaragoza (0.387)
Erfurt (ERF)	Aarhus (0.247), Beziers, Brno, Chios (0.753), Kalamata, Karup, Kavala, Kefallania, Ostrava, Preveza, Samos, Skiathos, Zaragoza
Friedrichshafen (FDH)	Aarhus, Alexandropoulos, Almeria (0.171), Bastia, Biarritz (0.241), Brno (0.022), Coruna, Kavala, Kefallania (0.516), Preveza, Samos, Skiathos, Timisoara (0.516) Zaragoza
Hannover (HAJ)	Alicante (0.3), Bilbao, Bordeaux, Faro, Gdansk, Girona, Goteborg (0.7), Heraklion, Ibiza, Larnaka, Lyon, Marseille, Nantes, Porto, Riga, Sevilla, Sofia, Thessaloniki, Toulouse, Valencia, Vilnius
Saarbrucken (SCN)	Aarhus (0.2692), Beziers (0.308), Brno, Chios, Kalamata, Karup, Kavala, Kefallania, Ostrava, Preveza, Samos, Skiathos, Zaragoza

Table 3. Treated Airports, Control Airports, and Synthetic Control Weights – Bordering Airports

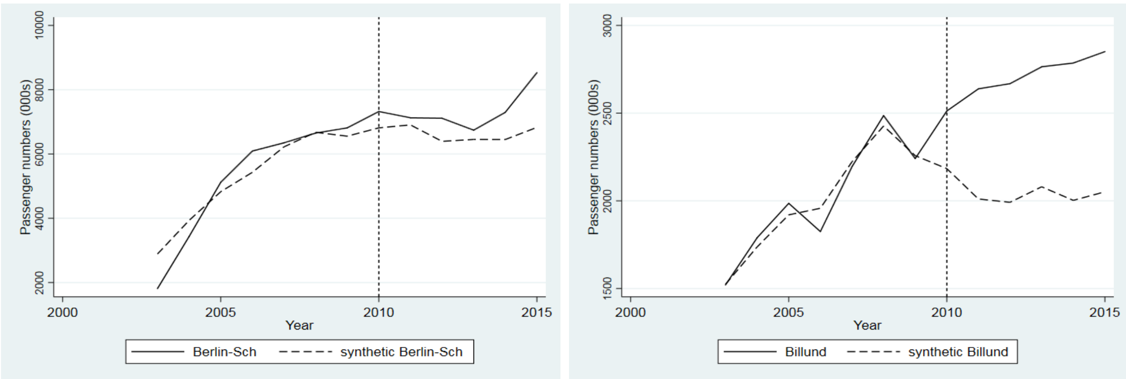
Treated Airport	**Control Airports (SC weights)**
Amsterdam (AMS)	Barcelona (0.441), Copenhagen, Geneva, Helsinki, Lisboa, London H (0.319), Madrid, Palma, Paris Orly, Paris CDG (0.178), Stockholm Main (0.062)
Eindhoven (EIN)	Bilbao, Bordeaux, Bratislava, Burgas, Chania, Faro, Gdansk, Goteborg, Heraklion, Ibiza, Kerkira, Kos, Larnaka, Lyon, Marseille, Menorca, Nantes, Pafos, Porto, Riga, Rodos, Santiago (0.067), Sevilla, Sofia, Stockholm (0.253), Stockholm B, Tallin, Thessaloniki, Toulouse, Valencia, Vilnius, Wroclaw (0.68)
Rotterdam (RTM)	Aalborg (0.209), Almeria, Asturias, Bastia, Biarritz, Bratislava, Burgas, Chania, Coruna, Granada, Jerez, Kerkira, Kos, Lille, Ljubljana, Malmo, Menorca, Montpellier, Murcia, Pafos, Reus, Santiago (0.053), Santorini, Stockholm, Stockholm B, Tallin, Timisoara, Varna, Vigo, Wroclaw, Zakintos (0.737)
Maastricht (MST)	Aarhus, Alexandropoulos, Beziers (0.254), Brno, Chios, Kalamata, Karup, Kavala, Kefallania, Nimes (0.746), Ostrava, Preveza, Samos, Skiathos, Zaragoza
Basel (BSL)	Alicante, Bilbao, Bordeaux, Budapest, Faro, Gdansk (0.51), Goteborg, Heraklion, Ibiza, Larnaka, Lyon, Marseille, Nantes, Nice, Porto, Prague, Riga (0.153), Rodos, Sevilla, Sofia, Thessaloniki, Toulouse, Valencia (0.337), Vilnius
Luxembourg (LUX)	Aalborg, Asturias, Bilbao, Bordeaux (0.024), Bratislava, Burgas, Chania, Gdansk, Granada, Jerez, Kerkira, Kos (0.071), Lille, Ljubljana, Malmo, Menorca, Montpellier (0.692), Murcia, Nantes, Pafos, Reus, Riga, Rodos, Santiago, Santorini, Sevilla, Sofia, Stockholm (0.213), Stockholm B, Tallin, Varna, Vigo, Vilnius, Wroclaw
Billund (BLL)	Asturias, Bilbao, Bordeaux, Bratislava, Burgas, Chania, Gdansk, Granada, Jerez, Kerkira, Kos, Larnaka (0.056), Lille, Ljubljana, Malmo, Menorca, Montpellier (0.532), Murcia, Nantes, Pafos, Reus, Riga, Rodos, Santiago (0.163), Santorini, Sevilla, Sofia, Stockholm (0.11), Stockholm B, Tallin, Thessaloniki, Varna, Vilnius (0.139), Wroclaw
Brussels (BRU)	Athens, Barcelona, Copenhagen, Geneva (0.209), Helsinki, Lisboa, Malaga, Nice (0.437), Paris Orly (0.355), Palma, Stockholm M
Zurich (ZRH)	Athens, Barcelona, Copenhagen (0.39), Geneva, Helsinki, Lisboa (0.436), Madrid (0.174), Malaga, Paris Orly, Palma, Stockholm Main
Metz (ETZ)	Aarhus (0.284), Alexandropoulos, Beziers, Brno, Chios, Esbjerg (0.628), Kalamata, Karpathos, Karup, Kavala, Kefallinia, Ostrava, Preveza, Samos (0.088), Skiathos
Szczecin (SZZ)	Aarhus, Alexandropoulos, Beziers (0.469), Brno (0.531), Chambery, Chios, Kalamata, Karpathos, Karup, Kavala, Kefallinia, La Rochelle, Nimes, Preveza, Samos, Skiathos
Prague (PRG)	Alicante, Athens, Budapest (0.637), Faro, Geneva (0.363), Helsinki, Ibiza, Lisboa, Lyon, Malaga, Marseille, Nice, Palma, Porto, Stockholm Main
Charleroi (CRL)	Aalborg, Almeria, Asturias, Bastia (0.34), Biarritz, Bordeaux, Bratislava, Burgas, Chania, Coruna, Faro (0.005), Gdansk (0.218), Girona, Goteborg, Granada, Heraklion (0.176), Jerez, Kerkira, Kos, Larnaka, Lille, Ljubljana, Malmo, Menorca, Murcia, Pafos, Porto (0.529), Reus, Riga (0.13), Rodos, Santiago, Sevilla, Sofia, Stockholm B, Tallin, Thessaloniki, Varna, Vigo, Vilnius, Wroclaw

Synthetic Control Estimations

Figures 1-2: Amsterdam and Basel



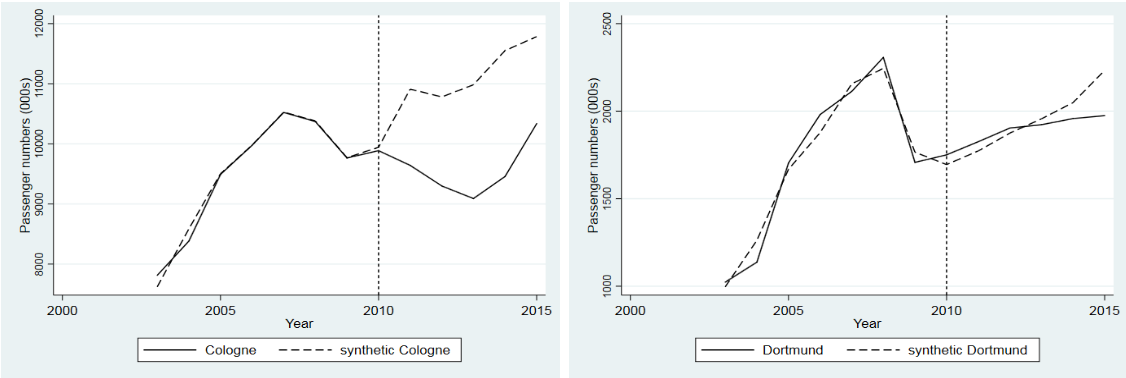
Figures 3-4: Berlin Schonefeld and Billund



Figures 5-6: Bremen and Brussels

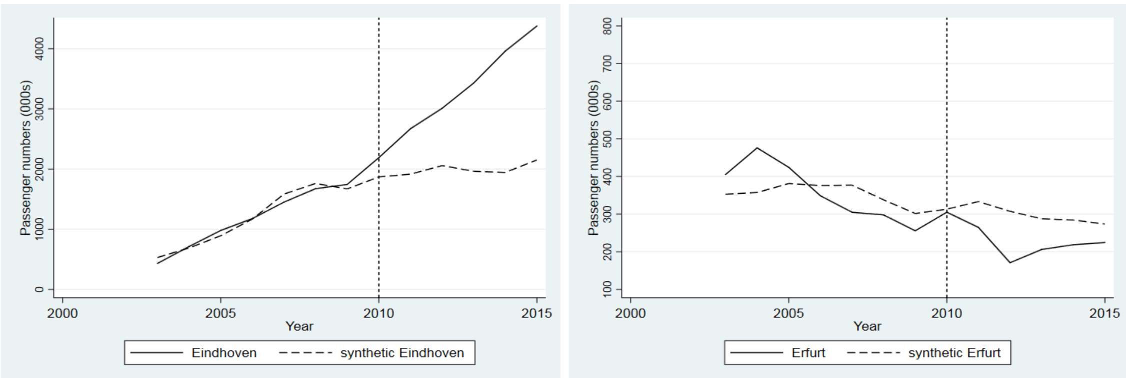
Figures 7-8: Berlin-Tegel and Charleroi

Figures 9-10: Cologne and Dortmund

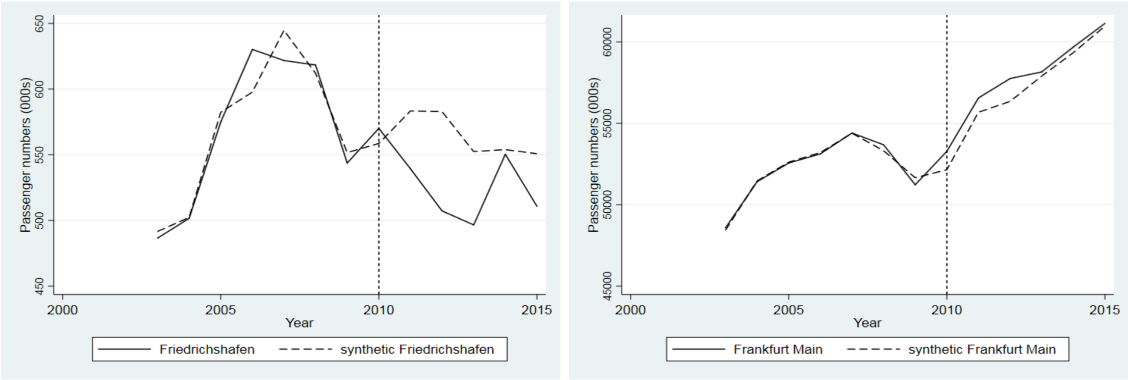


Figures 11-12: Dresden and Dusseldorf

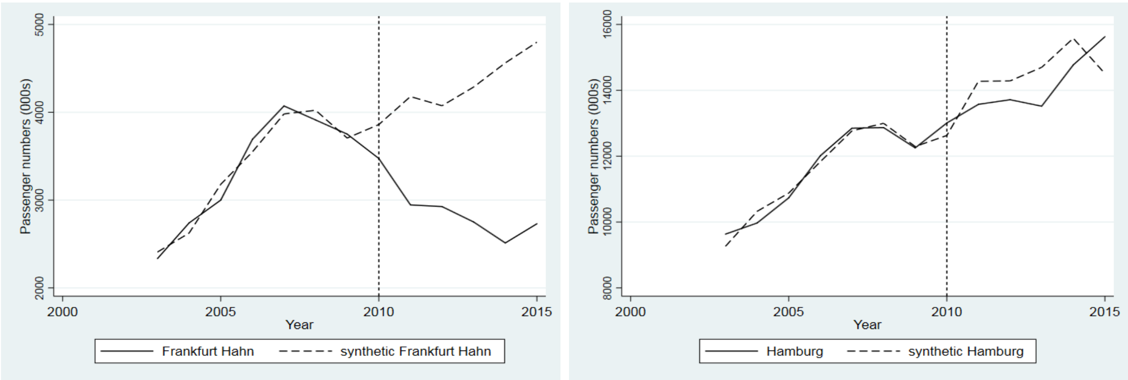
Figures 13-14: Eindhoven and Erfurt



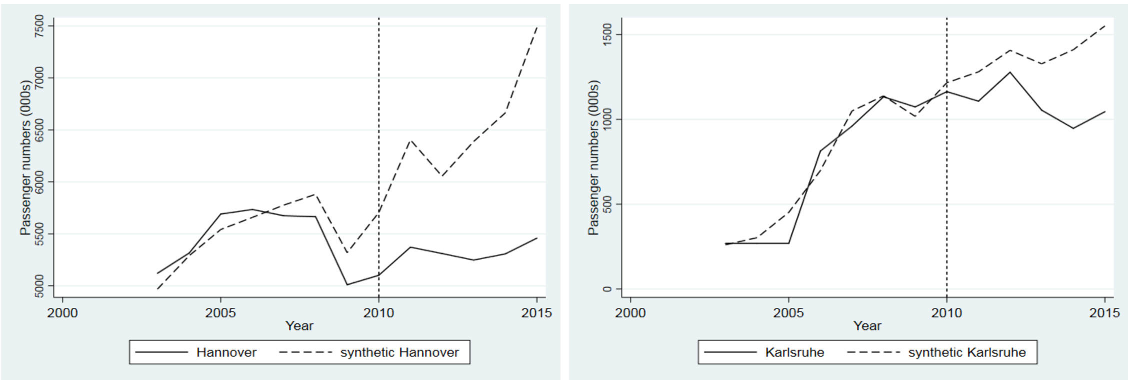
Figures 15-16: Friedrichshafen and Frankfurt Main



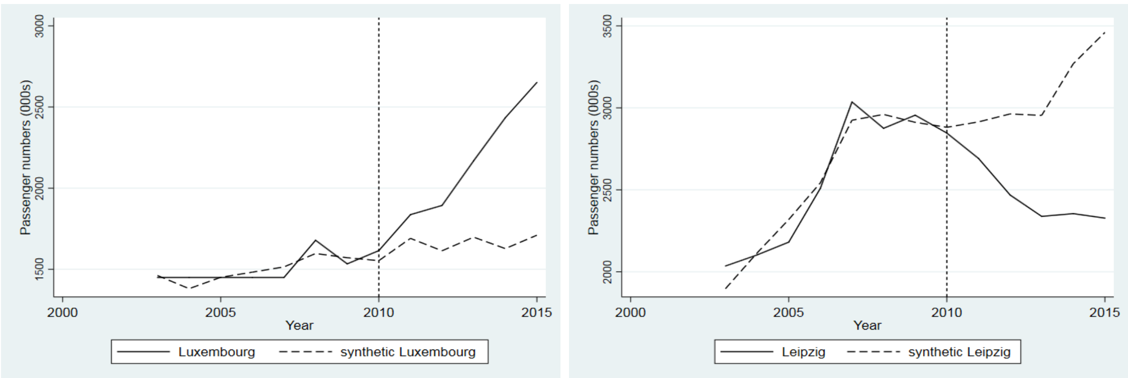
Figures 17-18: Frankfurt Hahn and Hamburg



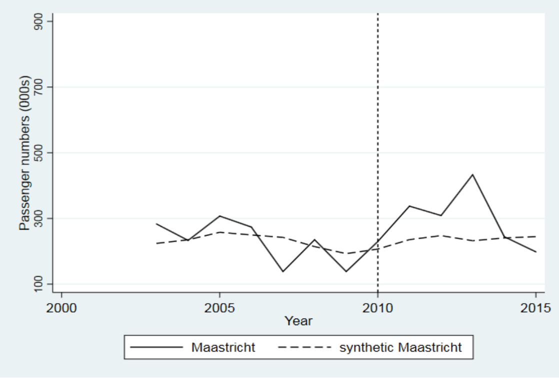
Figures 19-20: Hannover and Karlsruhe

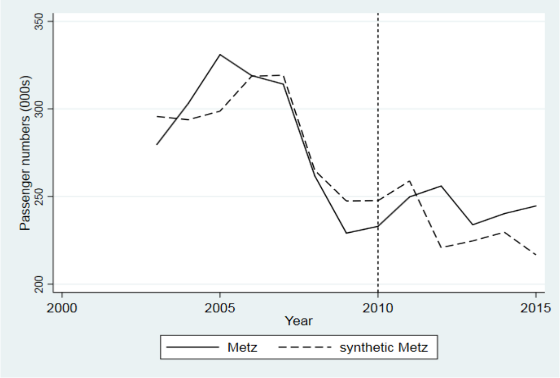


Figures 21-22: Luxembourg and Leipzig

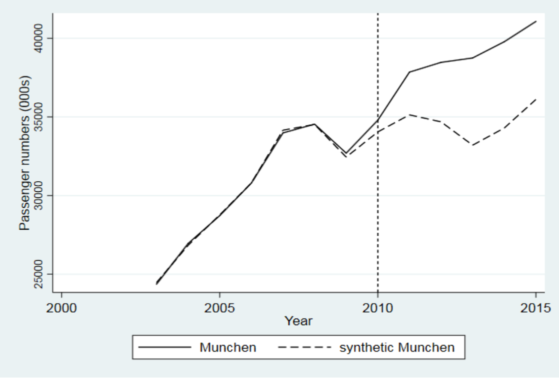


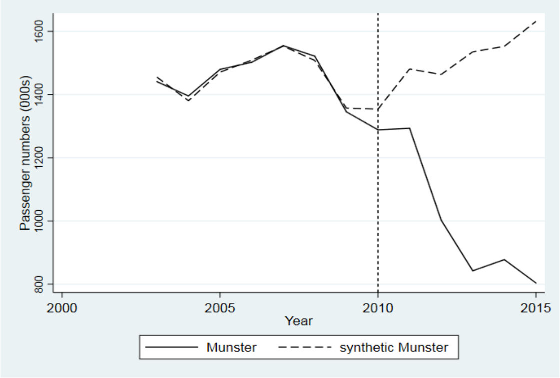
Figures 23-24: Maastricht and Metz



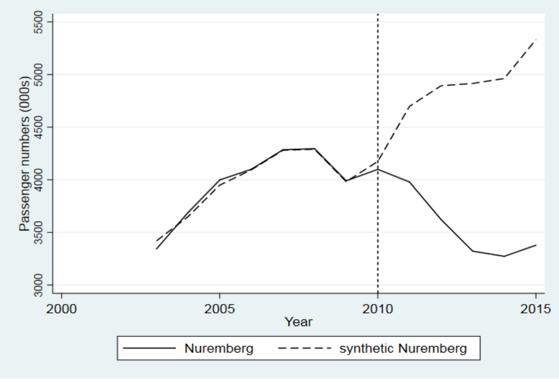


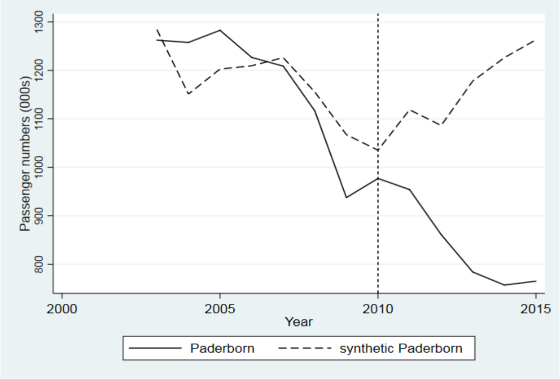
Figures 25-26: Munich and Munster



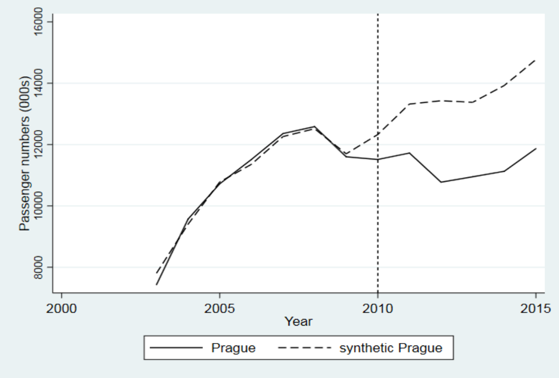


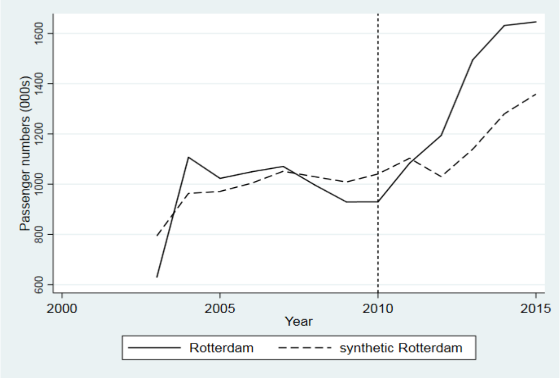
Figures 27-28: Nuremberg and Paderborn



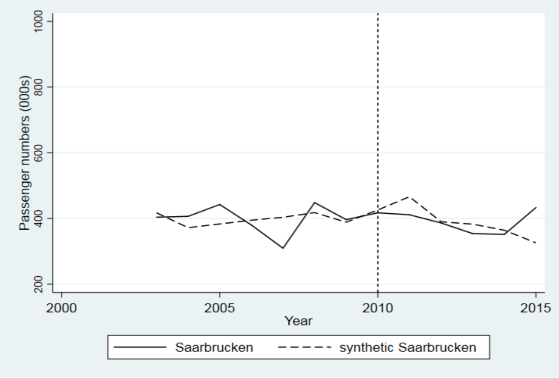


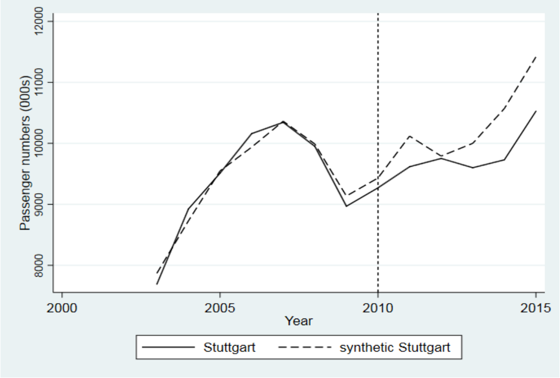
Figures 29-30: Prague and Rotterdam





Figures 31-32: Saarbrucken and Stuttgart





Figures 33-34: Szczecin and Zurich